THE KINEMATICS OF THE MAGELLANIC CLOUDS

B.E.WESTERLUND
Astronomical Observatory, Uppsala University
Box 515, S-75120 Uppsala, Sweden

Abstract. It is essential for our understanding of the evolution of the Magellanic System, comprising the Large and the Small Magellanic Cloud, the Intercloud or Bridge region and the Magellanic Stream, to know its motions in the past. The Clouds have a common envelope of neutral hydrogen; this indicates that they have been bound to each others for a long time. The Magellanic System moves in the gravitational potential of our Galaxy; it is exposed to ram pressure through its movement in the galactic halo. Both effects ought to be noticeable in their present structure and kinematics. It is generally assumed, but not definitely proven, that the Clouds have been bound to our Galaxy for at least the last 7 Gyr. Most models assume that the Clouds lead the Magellanic Stream. The interaction between the Clouds has influenced their structure and kinematics severely. The effects should be possible to trace in the motions of their stellar and gaseous components as pronounced disturbances. Recent astrometric contributions in this field show a great promise for the future if still higher accuracy can be achieved.

1. Introduction

The past history of the Magellanic Clouds is still veiled in obscurity. As all members of the Local Group they may have emerged from its barycentre. Whereas many of the dwarf galaxies in the Local Group may have had close encounters with either the Galaxy or M 31 but escaped (Mishra 1985), several, including the Large (LMC) and the Small (SMC) Cloud, were caught and are now satellites to either of the two giant galaxies in the Group. Shuter (1992) has suggested that the Clouds set out in a Hubble flow together with M 31 and the Galaxy, were subsequently attracted to M 31, and suffered a close collision with it $\sim$ 6 Gyr ago. The tidal acceleration in this collision projected them back toward the Galaxy and produced the velocity differentials required to establish the Magellanic Stream. Byrd *et*

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al. (1994) consider that the Magellanic Clouds left the M 31 neighbourhood $\sim$ 10 Gyr ago and were captured by our Galaxy $\sim$ 6 Gyr ago. According to Murai & Fujimoto (See Gardiner *et al.* 1994 for references) the Clouds may have been satellites to our Galaxy for up to 10 Gyr and always have been separate objects.

The Bridge between the SMC and the LMC contains HI gas but also young stars and associations with a common age of about 0.1 Gyr (Irwin *et al.* 1989). The Magellanic Stream extends from the Magellanic Clouds as an essentially continuous filament of HI about 100^o along a great circle as seen from the Galactic centre. There are six main concentrations, MS I to MS VI (Cf.Mathewson *et al.* 1987). No evidence for stars in the Stream have been found. CaII has been detected as well as interstellar lines(HI, CII, CIV, OI, MgII, SiII, Fe II) (cf. Penston 1982).

Several theories exist for the origin of the Magellanic Stream (See Mathewson *et al.* 1987, Liu 1992, Shuter 1992, Sofou 1994, Gardiner *et al.* 1994). In the ram pressure model the Intercloud Gas and the Magellanic Stream were produced in a collision between the LMC and the SMC about 0.4 Gyr ago. In the tidal model the Magellanic Stream was torn off from the SMC in an encounter with the LMC $\sim$ 1.5 Gyr ago which also coincided with a perigalactic passage.

2. The Distances of the Components of the Magellanic System

The Magellanic System covers a large area of the sky and a considerable distance in depth. Individual distances must be measured for its components. The uncertainties in the distance determinations arise mainly through the dependence of the criteria on the metallicities and ages of the involved objects and on the interstellar absorption in the line of sight.

2.1. THE INTERSTELLAR REDDENING, FOREGROUND AND INTRINSIC

Schwering & Israel (1991) have investigated the Galactic foreground colour excess towards the Magellanic Clouds on scales of 48 arcmin. Over the LMC the foreground reddening falls in the range$0.07 \leq E_{B-V} \leq 0.17$ mag. For the SMC the range is 0.07 to 0.09 mag. Bessell (1991), using various reddening determinations, derived a foreground excess in the SMC of $0.04 \leq E_{B-V} \leq 0.06$ mag and in the LMC of 0.04 to 0.09 mag. The average reddening within the SMC is probably $\sim$ 0.06 mag; there are regions with reddenings up to 0.3 mag. The average reddening within the LMC is similar but the variations are larger.

2.2. THE GEOMETRY OF THE MAGELLANIC CLOUDS

The LMC has long been regarded as a thin flat disk seen nearly face-on. Its east side is closer to us than the west. For the determination of the inclination (i) of its main body low-frequency observations, referring to non-thermal emission, are the most reliable. The thermal radio continuum emission receives strong contributions from discrete sources which are not necessarily in the main plane. The use of HI for determinations of i is questionable as HI has a complicated structure in and away from the main plane. From data summarized by Westerlund (1990) and from Schmidt-Kaler & Gochermann (1992) $35° \leq i \leq 45°$ appears as the most likely range for the tilt.

The SMC is extended in depth with the Wing and the NE section closer to us than the southern part so that its possible tilt and line of nodes have little relevance.

2.3. THE DISTANCES OF THE MAGELLANIC CLOUDS

TABLE 1. Determinations of the distance moduli of the Magellanic Clouds

LMC	SMC	Ref.
18.5	18.9	Westerlund (1990), review
18.19 ± 0.22	19.33 ± 0.31	Arellano Ferro *et al.* (1991): F supergiants
	18.9 ± 0.2	Barnes III *et al.* (1993): Cepheid HV 829
18.66 ± 0.05		Hughes & Wood (1990): old LPVs, P 200 d.
18.70 ± 0.23		Capaccioli *et al.* (1990): novae
18.4 ± 0.18		Hanuschik & Schmidt-Kaler (1991): SN1987A
18.50 ± 0.13		Panagia *et al.* (1991): SN1987A shell
18.38 ± 0.03		de Vaucouleurs (1993): Mean of 55 estimates
18.3 - 18.5		Reid & Freedman (1994): RR Lyr, NGC 2210

Table 1 summarizes recent determinations of the distance moduli of the LMC and the SMC. For estimates of the uncertainties in the moduli I refer to the table with individual data given by de Vaucouleurs (1993) and to Reid and Freedman (1994).

3. The Kinematics of the Magellanic System

Information about the conditions in the Magellanic System is now available from radio, infrared, optical, UV and X-ray observations. For the kinematics of the System the 21-cm HI observations have been particularly important.

3.1. TRANSVERSE MOTIONS OF THE LMC AND THE SMC

3.1.1. *Proper Motions of the LMC and the SMC*

All models proposed so far assume that the LMC and the SMC lead the Magellanic Stream and predict a proper motion for the LMC of between 1.5 and 2.0 mas yr^{-1}.

TABLE 2. Model motions of the LMC

Model	μ mas yr^{-1}	$v_{t,g}$ km s^{-1}	$V_{c,\odot}$ km s^{-1}	$R_\odot$ kpc
Murai & Fujimoto (1980)	1.7	288	250	10
Lin & Lynden Bell (1982)	2.0	373	244	9
Shuter(1992)	1.9	355	220	8.5
Liu (1992)	1.7	310	220	8.5
Gardiner*et al.* (1994)	1.8	287	220	8.5

TABLE 3. Proper motions of the Magellanic Clouds

$\mu_\alpha \cos\delta$ mas yr^{-1}	μ_δ mas yr^{-1}	Reference
0.91 ± 2.34	-0.23 ± 2.77	Tucholke, Hiesgen (1991), LMC
1.3 ± 0.6	$+1.1 \pm 0.7$	Kroupa *et al.* (1994), LMC, SMC
1.37 ± 0.25	-0.18 ± 0.25	Jones *et al.* (1994), LMC

Tucholke & Hiesgen (1991) measured absolute proper motions (498 reference galaxies, epoch span 15 yr). Kroupa *et al.* (1994) identified 35 PPM stars as members of the LMC and 8 of the SMC and derived proper motions from data spanning almost a century. The present values are consistent with bound as well as unbound orbits of the Magellanic Clouds. Jones *et al.* (1994) determined proper motions for 251 LMC members (92 reference galaxies, epoch span 14 yr) near NGC 2257, 8.5° from the LMC center, PA = 61°. The mean absolute proper motion of the LMC stars in this region is $\mu_\alpha = 0.120 \pm 0.028$ arcsec $\mathrm{century}^{-1}$, $\mu_\delta = 0.026 \pm 0.027$ arcsec $\mathrm{century}^{-1}$.

3.1.2. *Transverse Motions from Radial Velocities of the LMC and the SMC*

Feitzinger *et al.* (1977) used the difference in position angle between the kinematical (188.0° ± 2.6°) and photometric lines (168° ± 4°) of nodes to determine the transverse velocity. The same method was used by Meatheringham *et al.* (1988) and by Prévot *et al.* (1989). Hughes *et al.* (1991) found that the dynamics of the LMC is dominated by a single rotating disk and that all major populations of the Bar have solid- body rotation.

TABLE 4. Transverse motion of the LMC

Heliocentric velocity km s^{-1}	Galactocentric velocity km s^{-1}	Reference
	100	Feast *et al.* 1961; RV of stars and nebulae
275	143	Feitzinger *et al.* 1977
275 ± 65		Meatheringham *et al.*1988; gradients in RV
	150	Prévot *et al.* 1989; late- type supergiants
	200	Hughes *et al.*1991; HI, CO, PN, CHs, clusters
	236	Lin 1993; proper motions
	215 ± 48	Jones*et al.*1994; proper motions

The individual radial-velocity measurements are accurate to $\sim$ 10 –15 km s^{-1}; the individual proper motions are accurate to $\sim$ 3 mas yr^{-1}. At the distance of the LMC the latter corresponds to $\sim$ 700 km s^{-1}. If a 20 microarcsec accuracy can be achieved (see the GAIA concept at this conference) annual proper motions could be determined for LMC stars to better than $\sim$ 5 km s^{-1}.

3.2. THE INTERNAL MOTIONS IN THE LMC

Both the LMC and the SMC have been severely disturbed by interactions. Observed radial velocities may therefore not necessarily be interpreted as effects of rotation only.

3.2.1. *Local Disturbances in the Observed Radial Velocities in the LMC*

In their 21-cm line map of the LMC Rohlfs *et al.* (1984) note that the central region, $r < 1.5°$, is strongly perturbed by non-circular motions. There is a kink in the rotation curve; due to the HI void in the SGS LMC-4 area. The large cloud around the 30 Dor complex and extending south for about 2° is visible as a strong perturbation of the velocity field with a second component of lower radial velocity. A similar component is seen at the NW end of the Bar. These components may be connected with a warp of the LMC disk.In an extension of the Rohlfs *et al.* survey Luks & Rohlfs (1992) interpret the HI gas distribution as two rotating disks and no warps.

In the supergiant shell SGS LMC-4 the HI gas has three components (Dopita *et al.* 1985b): one in the plane, one above and one below it; the ejected gas has a velocity of 36 km s^{-1}. Supergiants have been found outside the LMC HI plane; they group around a velocity 35 km s^{-1} larger than the HI velocity in their neighbourhood or around a 34 km s^{-1} smaller velocity (McGee 1964), i.e. with velocities similar to the expansion velocity of SGS LMC-4. This may be typical for the motion of young objects forced out of the plane.

3.2.2. *The Kinematics of the Youngest Population in the LMC*

Images of the LMC in any wavelength region are dominated by radiation from its Extreme Population I constituent (stellar associations, supergiants, etc.) or the connected gas (HII regions, HI complexes, molecular clouds) and dust. They display the regions of recent star formation as an asymmetric pattern, not completely at random but with some structure. During the past 30 years many attempts have been made to interpret the observations of the youngest population as showing a spiral-arm structure. Two lines of thought regarding the structure of the LMC appear to develop independent of each others: (1).– The radio centre is given the role played by the nucleus in our Galaxy, i.e. as the centre of rotation and mass for all classes of objects.– In a recent investigation Luks & Rohlfs (1992) found two rotating disks in their HI maps: one extending over all of the LMC with 72 % of the HI gas and a lower-velocity component with 19 %. The rotation curve of the major component is symmetric. It has its centre at $5^h12^m.8$, - 69°.1 (1950), i.e. 1.2° from the centre of the Bar.The low-velocity component contains the complex south of 30 Dor and a lobe N and W of it with the 30 Dor nebula as a link between the two lobes. Its distance above the main disk is at least 250 – 400 pc. (2).– The 30 Doradus nebula is considered as the origin of the spiral arms.– A number of well separated sources in the 1.4 GHz radio continuum map form long ridges suggested to originate in the 30 Doradus nebula (Feitzinger *et al.* 1987). The ridges correlate well with a series of blobs in the 100μm emission in the IRAS maps and with the UV brightness distributions. Most outstanding is the chain of OB associations and HII regions, " a bright and sharply defined spiral", through the Bar towards the NW.

3.2.3. *The Kinematics of the Old and Intermediate-Age Clusters in the LMC*

Doubts on the LMC as a single uniformly rotating disk arose from an investigation of the RVs of 59 clusters by Freeman *et al.* (1983). Clusters younger than 1 Gyr had motions similar to the gas in their vicinity and shared the rotation solution found from HI and HII region velocities (line-of-sight velocity dispersion 15 km s^{-1}, rotation amplitude 37 ±5 km s^{-1}, galactocentric systemic velocity 40 ± 3 km s^{-1}, and a line of nodes in PA 1° ± 5°. Also the intermediate-age clusters formed a flattened system. The oldest clusters, age ~ 10 Gyr, had a line-of-sight dispersion of 16 km s^{-1}, a rotation amplitude of 54±7 km s^{-1}, a systemic velocity of 38 ± 4 km s^{-1}, and a line of nodes in PA 44° ± 6°. The oldest LMC clusters appear to rotate in a disk separate from that of the other populations but do not form a spherical halo population.

Schommer *et al.* (1992) analyzed RVs for 83 star clusters in the LMC. About one half of the clusters are more than 5° from the center. The outer cluster sample and the inner intermediate age clusters form a disk aligned with the inner HI kinematics and the outer LMC isophote major-axis position angle.The oldest clusters rotate with an amplitude comparable to that of the younger disk with a small velocity dispersion. A single rotating disk solution fits the old and intermediate-age clusters and other tracers (no need for an additional "tilted disk" system). In the inner 2° the old clusters exhibit peculiar velocities, as do the CH stars and the old LPVs, possibly due to perturbations from the Bar. The rotation curve does not show signs of a Keplerian falloff out to at least 5 – 6 disk scale lengths, implying the existence of dark matter associated with the LMC.

3.2.4. *The Kinematics of the Planetary Nebulae and the Oldest Stellar Field Populations in the LMC*

Meatheringham *et al.* (1988) have derived a rotation solution for the PN in the LMC essentially identical with that of the HI but the vertical velocity dispersion of 19.1 km s^{-1} is much greater than the 5.4 km s^{-1} found for HI. The larger dispersion of the PN is consistent with the action of orbital diffusion over the lifetime of the PN. The bulk of the PN cannot represent a halo population.

Hughes *et al.* (1991) have obtained RVs for a significant sample of LPVs and applied a kinematic analysis to a wide range of LMC populations (HI, CO, PN, CH stars, clusters, LPVs). The oldest LPVs (~ 10 Gyr) were found to have a high velocity dispersion and a low rotational velocity, proving that they belong to a flattened spheroid population (maximum height $\leq$ 2.8 kpc); may be part of a disk population ~ 4 Gyr old. The dynamics of the LMC is dominated by a single rotating disk.

The velocity distribution derived by Hartwick & Cowley (1991) from radial velocities for 81 CH stars appears assymetrical. Two groups stars may exist, one of which may have about the same age as the oldest LPVs and belong to the spheroid population. The other may be associated with a flattened-disk system; it contains stars with luminosities up to $M_{bol} = -6$ or brighter. They may belong to an AGB population as young as ~ 0.1

Gyr(Suntzeff *et al.* 1993) or be products of binary mergers, age a few Gyr (Feast 1992).

3.3. THE INTERNAL MOTIONS IN THE SMC

The early attempts to interpret the SMC as a rotating galaxy with a spiral structure have been replaced by questions about its extension in depth and/or about the kind and extent of its fragmentation.

3.3.1. *The Extension of the SMC in Depth*

The SMC was first suspected to have an appreciable extent in depth by Johnson (1961). Azzopardi (1982) showed that the A, B, O supergiants in the SMC have an appreciable spread in distance, up to 7 kpc. At least two stellar groupings may thus exist in the SMC. Feast *et al.* (1961) found no convincing rotational effects and concluded that their results could be represented by a random scatter around a mean velocity of 166 ± 3 km s^{-1}.

Analyses of the structure of the SMC based on new extensive radio, optical and UV observations show that several velocity groups exist. In a series of investigations Mathewson *et al.* (See Mathewson *et al.* 1988 for references) have shown that two separate entities exist in the HI distribution in the SMC, each with its own stellar and nebular populations. They may have formed when the SMC was torn apart in the encounter with the LMC $\sim$ 0.2 Gyr ago into a low-velocity fragment, the SMC Remnant (SMCR), in front of a higher-velocity fragment, the Mini-Magellanic Cloud (MMC). Cepheids were found in the range 43 and 75 kpc with two 6 kpc deep components centered 12 kpc apart. A further detailed study of Cepheids in the SMC Bar combined with a high resolution HI survey of this region confirmed that the SMC has a depth of $\sim$ 20 kpc and that the NE section of the Bar is 10 –15 kpc closer than the southern. An extension of the SMC in depth has also been proposed from observations of red stars aged more than 1 Gyr (see Hatzidimitriou & Cannon 1993).

Martin *et al.* (1989) carried out an extensive discussion of the structure and motions of the SMC based on the HI velocity distribution, on accurate RVs of 307 young stars and 35 HII regions, and on very high spectral resolution profiles of interstellar absorption lines. The HI in the Bar was found to consist of 4 components: a very low (VL) component in the SW, a low (L) major component covering the southern half of the SMC, a high velocity (H) component everywhere except in the SW, and a weak very high (VH) velocity component mainly in the NE. The L and H components correspond more or less to the SMCR and MMC. The main H complex is behind the L complex. Most of the young SMC stars lie within a depth of

$\leq$ 10 kpc. Interstellar CaII is seen at higher and lower velocities than the HI lines. (cf. Fitzpatrick & Savage 1985).

3.3.2. *The Kinematics of the Planetary Nebulae, C Stars and Halo Giants in the SMC*

The PN in the SMC form an unstructured spheroidal population apparently associated with the Bar and with the centroid at $0^h49^m.7$, $-73°.5$ (1950) and a mean $RV_{GSR} = -17$ kms^{-1} (Dopita *et al.* 1985a). No evidence was found of any organized rotation, nor any bimodal velocity distribution of the kind observed by Torres & Caranza (1987) and others. Infrared spectroscopy by Hardy *et al.* (1989) with an individual precision of $\sim$ 1.8 km s^{-1} show that the C stars behave kinematically like the PN with which they share the mean velocity as well as a velocity dispersion of $\sim$ 27 km s^{-1}. No evidence was found of a velocity splitting, nor of rotation of the main body. C stars and PN may belong to a spheroidal-like system.

In their study of the metallicity and RV of SMC halo giants Suntzeff *et al.* (1986) compared the kinematics of the NGC 121 field with the SMC in general They found a velocity of -29 km s^{-1} for these stars. This is significantly smaller than the velocities of $+2 \pm 3$ km s^{-1} for the main body of the SMC and $+ 21$ km s^{-1} for the K1 region east of the SMC Bar found by Ardeberg & Maurice (1979). The three values give together the impression of a small gradient in stellar RV about orthogonal to the HI major axis. However, they show more likely the double-peaked velocity structure in the SMC.

The present data for PN, C stars, and metal-poor giants appear to show that the near collision with the LMC $\sim$ 0.2 Gyr ago did leave the older stellar component roughly spheroidal whereas the gaseous component was drawn out along our line of sight.

3.4. THE MOTIONS IN THE BRIDGE REGION AND IN THE MAGELLANIC STREAM

The RV of the Stream with respect to the Galactic Centre becomes increasingly more negative from 0 km s^{-1} at MS I to -200 km s^{-1} at MS VI. There is a sharp discontinuity in velocity of $\sim$ 100 km s^{-1} between the top of the Intercloud region and MS I (Mathewson *et al.* 1987). Other components are also seen in HI as overlapping the main Stream. Several of them appear to be typical high-velocity clouds (Morras 1985). The Stream is following behind the Magellanic Clouds.

References

Ardeberg A., Maurice E., 1979, *A&A* **77**, 277

Arellano Ferro A., Mantegazza L., Antonello E., 1991, *A&A* **246**, 341
Azzopardi M., 1982, *C.R. Journées Strasbourg* **4**, p.20
Barnes III Th.G., Moffett Th.J., Gieren W.P., 1993, *ApJ* **405**, L51
Bessell M.S., 1991, *A&A* **242**, L17
Byrd G., Valtonen M., McCall M., Innanen K., 1994, *AJ* **107**, 2055
Capaccioli M., Della Valle M., D'Onofrio M., Rosino L., 1990, *ApJ* **360**, 63
Cowley A.P., Hartwick F.D.A., 1991,*ApJ* **373**, 80
De Vaucouleurs G., 1993, *ApJ* **415**, 10
Dopita M.A., Ford H.C., Lawrence C.J., Webster B.L., 1985a, *ApJ* **296**, 390
Dopita M.A., Mathewson D.S., Ford V.L., 1985b, *ApJ* **297**, 599
Feast M.W., 1992, *New Aspects of Magellanic Cloud Research* , p. 239
Feast M.W., Thackeray A.D., Wesselink A.J., 1961,*MNRAS* **122**, 433
Feitzinger J.V., Isserstedt J., Schmidt-Kaler Th., 1977, *A&A* **57**, 265
Feitzinger J.V., Haynes R.F., Klein U., Wielebinski R., Perschke M.,1987, *Vistas Astr.* **30**, 243
Fitzpatrick E.L., Savage B.D., 1985, *ApJ* **292**, 122
Freeman K.C., Illingworth G., Oemler Jr.A., 1983, *ApJ* **272**, 488
Gardiner L.T., Sawa T., Fujimoto M., 1994, *MNRAS* f 266, 567
Hanuschik R.W., Schmidt-Kaler Th., 1991, *A&A* **249**, 36
Hardy E., Suntzeff N.B., Azzopardi M., 1989, *ApJ* **344**, 210
Hatzidimitriou D., Cannon R.D., 1993, *New Aspects of Magellanic Cloud Research* , p. 17
Hughes S.M.G., Wood P.R., 1990, *AJ* **99**, 784
Hughes S.M.G., Wood P.R., Reid N., 1991, *AJ* **101**, 1304
Irwin M.J., Demers S., Kunkel W.E., 1990, *AJ* **99**, 191
Jones B.F., Klemola A.R., Lin D.N.C., 1994, *AJ* **107**, 1333
Kroupa P., Roeser S., Bastian U., 1994, *MNRAS* **266**, 412
Lin D.N.C., 1993, *BAAS* **25**, 783
Lin D.N.C., Lynden-Bell, D., 1982, *MNRAS* **198**, 707
Liu Y.-z., 1992, *A&A* **257**, 505
Luks Th., Rohlfs K., 1992, *A&A* **263**, 41
McGee R.X., 1964, *Aust. J.Phys.* **17**, 515
Mathewson D.S., Wayte S.R., Ford V.L, Ruan K., 1987, *Proc.Astron. Soc. Aust.* **7**, 19
Mathewson D.S., Ford V.L., Visvanathan N., 1988, *ApJ* **333**, 617
Meatheringham S.J., Dopita M.A., Ford H.C., Webster B.L., 1988, *ApJ* **327**, 651
Mishra R., 1985, *MNRAS* **212**, 163
Morras R., 1985, *AJ* **90**, 1801
Panagia N., Gilmozzi R., Macchetto F., Adorf H.-M., Kirshner R.P., 1991, *ApJ* **380**, L23
Penston M.V., 1982, *Observatory* **102**, 174
Prévot L., Rousseau J., Martin N., 1989, *A&A* **225**, 303
Reid N., Freedman W., 1994, *MNRAS* **267**, 821
Roeser S., Bastian U., 1993, *Bull. Inf. CDS* **42**, 11
Schmidt-Kaler Th., Gochermann J., 1992, *ASP Conf. Ser.* **30**, 203
Schommer R.A., Olszewski E.W., Suntzeff N.B., Harris H.C., 1992, *AJ* **103**, 447
Schwering P.B.W., Israel F.P., 1991, *A&A* **246**, 231
Shuter W.L., 1992, *ApJ* **386**, 101
Sofue Y., 1994, *Univ. Tokyo Preprint No. 94-07*
Suntzeff N.B., Friel E., Klemola A., Kraft R.P., Graham J.A., 1986, *AJ***91**, 275
Suntzeff N.B., Phillips M.M., Elias J.H., Cowley A.P., Hartwick F.D.A., Bouchet P., 1993, *PASP* **105**, 350
Torres G., Carranza G.J., 1987, *MNRAS* **226**, 513
Tucholke H.-J., Hiesgen M., 1991, *Proc IAU Symp. 148* (eds. R.Haynes, D.Milne), p.491
Westerlund B.E., 1990, *A&AR* **2**, 29